Biolinguistic Minimalism and Language Evolution

AUTHOR(S):

Fujita, Koji

Biolinguistic Minimalism and Language Evolution

Koji Fujita
Kyoto University

1

"... an evolutionary novelty may result from the combination of two pre-existing parts with unrelated functions."

- M. Ridley

2

"Evolution has recruited for language purposes brain structures that performed other functions in non-human primates."

- T. W. Deacon

"Language can be viewed as a new machine that evolved initially in the service of completely different functions."

- E. Bates

3

Original Function vs. Current Utility

- Language as a tool for communication is an exaptation of language for thought.
- 'Current language with some function' is an exaptation of 'original language with no function.'

4

- The functions of the components that jointly constituted the language faculty later in the hominin evolution may have had nothing to do with the current or original function(s) of language.
- Animal communication may have only an indirect bearing on language evolution.

5

- Organization
- Part I: Conceptual Issues
- Part II: Recursion in Minimalist Syntax
- Part III: Towards a Comparative Study

6

Part I
Conceptual Issues

7

Biolinguistics:

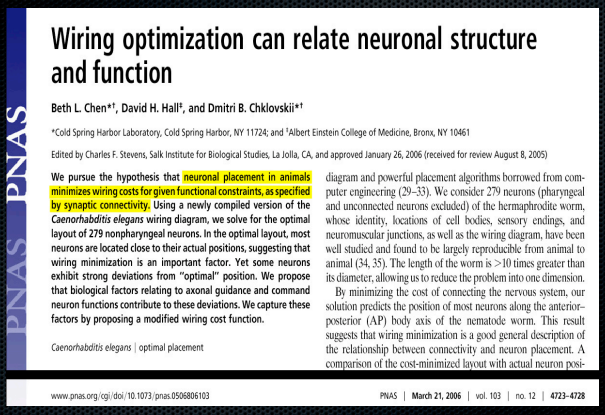
- Naturalization (or biologization) of human language faculty
  - Biosyntax
  - Biosemantics, etc.

8

Minimalist Program:

- Minimization of UG by reduction to natural laws ("the third factor").
- Perfection, Optimality, Economy, Simplicity, and elegance in nature and language (as a natural object)
- Methodological Naturalism
- Strong Minimalist Thesis

9



PNAS PNAS

Wiring optimization can relate neuronal structure and function

Beth L. Chen*†, David H. Hall‡, and Dmitri B. Chklovskii*†

*Cold Spring Harbor Laboratory, Cold Spring Harbor, NY 11724; and ‡Albert Einstein College of Medicine, Bronx, NY 10461

Edited by Charles F. Stevens, Salk Institute for Biological Studies, La Jolla, CA, and approved January 26, 2006 (received for review August 8, 2005)

We pursue the hypothesis that neuronal placement in animals minimizes wiring costs for given functional constraints, as specified by synaptic connectivity. Using a newly compiled version of the *Caenorhabditis elegans* wiring diagram, we solve for the optimal layout of 279 nonpharyngeal neurons. In the optimal layout, most neurons are located close to their actual positions, suggesting that wiring minimization is an important factor. Yet some neurons exhibit strong deviations from "optimal" position. We propose that biological factors relating to axonal guidance and command neuron functions contribute to these deviations. We capture these factors by proposing a modified wiring cost function.

Caenorhabditis elegans | optimal placement

diagram and powerful placement algorithms borrowed from computer engineering (29–33). We consider 279 neurons (pharyngeal and unconnected neurons excluded) of the hermaphrodite worm, whose identity, locations of cell bodies, sensory endings, and neuromuscular junctions, as well as the wiring diagram, have been well studied and found to be largely reproducible from animal to animal (34, 35). The length of the worm is >10 times greater than its diameter, allowing us to reduce the problem into one dimension.

By minimizing the cost of connecting the nervous system, our solution predicts the position of most neurons along the anterior–posterior (AP) body axis of the nematode worm. This result suggests that wiring minimization is a good general description of the relationship between connectivity and neuron placement. A comparison of the cost-minimized layout with actual neuron posi-

www.pnas.org/cgi/doi/10.1073/pnas.0506806103

10

11

"The physicist's problem is the problem of ultimate origins and ultimate natural laws. The biologist's problem is the problem of complexity."

"the biologist tries to explain the workings, and the coming into existence, of complex things, in terms of simpler things. He can regard his task as done when he has arrived at entities so simple that they can safely be handed over to physicists."

- R. Dawkins

12

Biolinguistic Minimalism

... tries to explain the Design, Development and Evolution of human language in terms of things simple enough to be handed over to physics.

13

"The presumption of perfection in language seems unwarranted and implausible"

- A. Kinsella & G. Marcus

"evolution is often more about alighting on something that happens to work than what might in principle work best or most elegantly; it would be surprising if language, among evolution's most recent innovations, was any different."

- G. Marcus

14

"Your theory of language evolution depends on your theory of language"

- R. Jackendoff

... and on your theory of biological evolution, too.

Furthermore, your theory of language depends on your theory of language evolution and biological evolution.

15

- Language evolution is an instance of biological evolution.
- If your theory of biological evolution does not explain language evolution, then it needs a serious reconsideration.

16

- Logical Problem of Language Acquisition (Plato's problem)
- Explanatory Adequacy
- Logical Problem of Language Evolution (Darwin's problem)
- Evolutionary Adequacy

17

- Modern Synthesis (Neo-Darwinism)
  - Adaptationist
  - Natural Selection as the First Resort
  - Gradualist
  - Functionalist
  - Genetic Determinism
- Expanded Synthesis (Neo-Neo-Darwinism)
  - Non-adaptationist
  - NS as the Last Resort
  - Punctuated Equilibrium (saltationist)
  - Formalist
  - Epigenetic View
  - Language as a Spandrel

18

Against Hyper-Selectionism (Ultra-Darwinism)

"Natural selection can only function within a 'channel' of options afforded by natural law ..."

"... the whole process of evolution is shaped by physical processes ..., yielding many properties that are casually attributed to selection."

"Darwin ... taking explicit note of a range of possibilities, including non-adaptive modifications and unselected functions determined from structure ..."

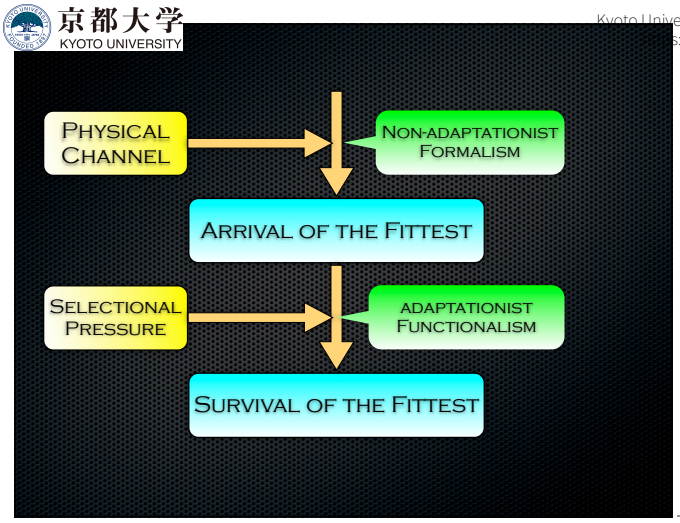
- N. Chomsky

19

"Suppose that some ancestor, perhaps about 60,000 years ago, underwent a slight mutation rewiring the brain, yielding Merge. Then he or she would at once have had available an infinite array of structured expressions for use in thought (planning, interpretation, etc.), gaining selectional advantages transmitted to offspring, capacities that came to dominate, yielding the dramatic and rather sudden changes found in the archeological record."

- N. Chomsky

20



21

APTATION	ADAPTATION	NATURAL SELECTION SHAPES THE CHARACTER FOR A CURRENT USE.
	EXAPTATION	A CHARACTER, PREVIOUSLY SHAPED BY NATURAL SELECTION FOR A PARTICULAR FUNCTION, IS CO-OPTED FOR A NEW ONE. (PREADAPTATION)
		A CHARACTER WHOSE ORIGIN CANNOT BE ASCRIBED TO THE DIRECT ACTION OF NATURAL SELECTION (A NON-ADAPTATION) IS CO-OPTED FOR A CURRENT USE.

22

Figure 2. Peacock with a highly ornamented tail which, like the male quetzal's tail, evolved by female choice. If some "eyes" are removed from his tail, he becomes less attractive to peahens. It is hard to imagine how such an enormous encumbrance would be compatible with escape from predators, and indeed further enlargement of the tail may have been constrained by natural selection.

23

- D'ARCY THOMPSON:

  PHYSICAL CONSTRAINTS ON GROWTH AND FORM, MORPHOLOGICAL TRANSFORMATION

- ALAN TURING:

  CHEMICAL BASIS OF MORPHOGENESIS
  REACTION-DIFFUSION MODEL

- C. WADDINGTON:

  CANALIZATION, GENETIC ASSIMILATION

- S. KAUFFMAN:

  SELF-ORGANIZATION, AUTO-EVOLUTION

24

"We want to see how ... the forms of living things, and of the parts of living things, can be explained by physical considerations, and to realise that in general no organic forms exist save such as are in conformity with physical and mathematical laws."

- D'Arcy W. Thompson

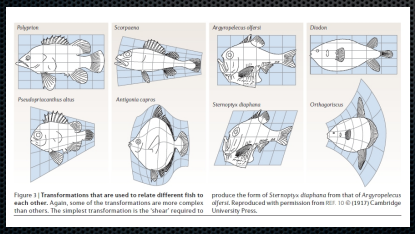


Figure 1 | **Transformations that are used to relate different fish to each other.** Again, some of the transformations are more complex than others. The simplest transformation is the 'shear' required to produce the form of *Sternoptyx diaphana* from that of *Argyropelecus olfersi*. Reproduced with permission from REF. 10 © (1917) Cambridge University Press.

25

Canalization

- "development is robust to changes in genotype and environment"

  - M. L. Siegal & A. Bergma. Waddington's canalization revisited: developmental stability and evolution.

- "individuals are somehow buffered, or canalized, against genetic and environmental variation."

  - J. E. Niven. Channelling evolution – canalization and the nervous system.

26

Evo-Devo

- "a major research programme whose findings put into question some concepts lying at the core of the Synthetic Theory"
- "a 'revolution' in biology, one in which the existing genetic determinism will give way to a new conceptual understanding of the complexity of living organisms"
- "focused on how changes in development bring about evolutionary changes"

  - S. Urdy & R. Chirat. Snail shell coiling (re-)evolution.

27

- Biolinguistic minimalism seeks a teleomatic explanation of the language design.
- Apparent goal-directedness:
- Teleology
- Teleonomy
- Teleomaticity

"Language is like a snowflake."

28

Main points made so far:

- Language evolution must be studied on the basis of a specific paradigm of evolutionary biology.
- Language evolution works as a useful tool for evaluating one's view of biological evolution in general.
- Biolinguistic minimalism adopts the new paradigm of expanded synthesis and evo-devo.

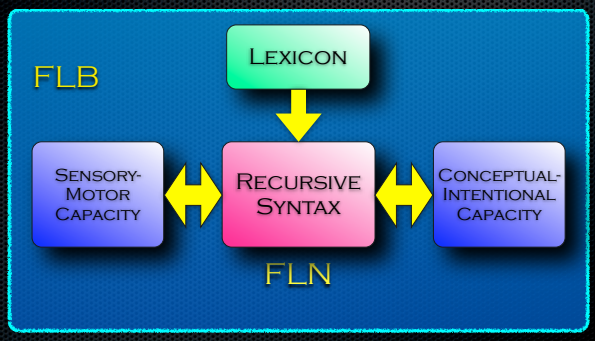
29

Part II

Recursion in Minimalist Syntax

30

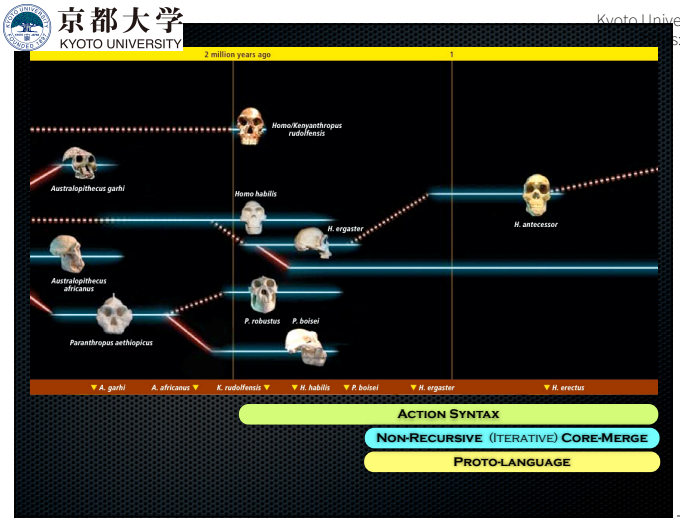
Human Language Faculty: Basic Design



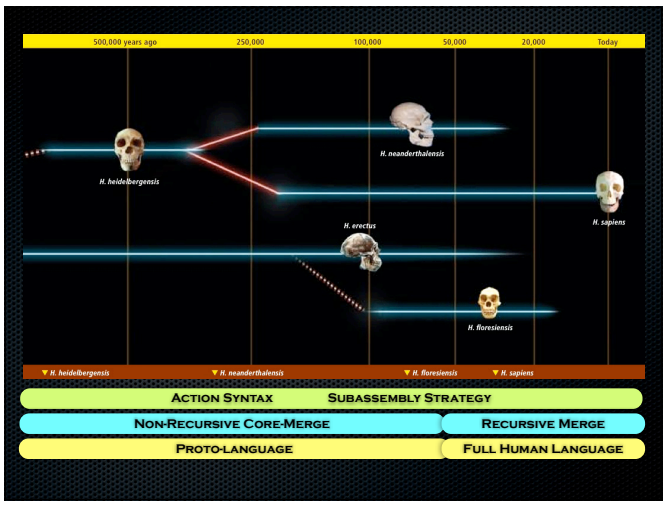
31

From Proto-Language to Full Human Language

32



33



34

- "A key component of FLN is a computational system (narrow syntax) that generates internal representations and maps them into the sensory-motor interface ... and into the conceptual-intentional interface"
- "FLN comprises only the core computational mechanisms of recursion as they appear in narrow syntax and the mappings to the interfaces"

- Hauser, Chomsky & Fitch

35

- Apparently, FLN should include:
  - Recursive Syntax
  - Recursive Mapping to the Interfaces
  - The Lexicon
- Core issues of language evolution boil down to the origins of these capacities.

36

- NO CLEAR EVIDENCE FOR LANGUAGES THAT DEMONSTRABLY LACK RECURSION

- B. HEINE & T. KUTEVA

- RECURSION IS ABSENT IN PIRAHÃ.

- D. EVERETT

- MANY LANGUAGES HAVE NO, OR VERY CIRCUMSCRIBED RECURSION IN THEIR SYNTAX.

-N. EVANS & S. LEVINSON

- RECURSION IS JUST A THEORETICAL ARTIFACT.

- D. BICKERTON

37

- SYNTACTIC RECURSION = RECURSIVE MERGE
  - REPRESENTATIONAL RECURSIVENESS: A CATEGORY APPEARS REPEATEDLY INSIDE A PHRASE OF THE SAME CATEGORY.
  - DERIVATIONAL RECURSIVENESS: THE ELEMENTARY COMBINATORIAL OPERATION MERGE APPLIES RECURSIVELY TO ITS OWN OUTPUT.

38

(1) [JOHN [SAW MARY]].

(DERIVATIONALLY RECURSIVE)

(2) [BILL [THINKS [JOHN [SAW MARY]]]].

(REPRESENTATIONALLY RECURSIVE, TOO)

39

PIRAHÃ: A LANGUAGE WITHOUT RECURSION?

(1) TI GÁI -SAI KÓ'OI HI KAHÁP -ÍÍ
I SAY-OLD.INFO KÓ'OI HE LEAVE-INTENTION
'I SAY. KÓ'OI WILL LEAVE.' (PARATAXIS)

- D. L. EVERETT

"... THE SPEAKERS OF THIS LANGUAGE AREN'T MAKING USE OF A CAPACITY THAT THEY SURELY HAVE ..."

- N. CHOMSKY

40

"Unbounded Merge is not only a genetically determined property of language, but also unique to it."

"For both evolution and development, there seems to be little reason to suppose that there were precursors to unbounded Merge."

- N. Chomsky

41

- Core-Merge: (A, B) → {A, B}

- Recursive Merge: (C, {A, B}) → {C, {A, B}}

42

- Merge is triggered by the "Edge Feature."
- Only lexical items have the EF.
  (Only lexical items can undergo Merge.)
- Recursive Merge is possible only when the EF remains visible to the computational system.

... But how did the EF evolve?

43

- Suppose in a language C's EF is always erased once satisfied; the language will have no clausal embedding – a situation compatible with the Pirahã facts.

44

(1) EF invisible

(2) EF visible

Labeling

(3) Recursive Merge applies

- Label 

- Merge (the, dog) = {the, dog}
- Label {the, dog} = {the, {the, dog}}

- Core-Merge + Label = Recursive Merge
- Only Label, not Recursive Merge, belongs to FLN.
- Core-Merge is not unique to language.

... But how did Label evolve?

- N. Fukui: Label = Embed
- Merge defines a Base Set {A, B} to which subsequent operations may apply.
- Embed takes one member of this BS (A) and forms a union of this member and the BS.
- Embed (A, {A, B}) = A ∪ {A, B} = {A, {A, B}}

- Label = Recursive Merge
  - Merge (C, {A, B}) = {C, {A, B}}
  - Label (A, {A, B}) = {A, {B, C}}
- No need to seek the origin of Label independently of Merge.

49

- To the extent that Move = Internal Merge, Label is a strictly local version of Move.

Merge (C, {A, B}) = {C, {A, B}}:

(1) External Merge, where C is external to A and B.
(2) Internal Merge, where C is internal to A or B.
(3) Label, where C is A or B.

50

- Label always gives rise to Endocentricity.
- But what about exocentric compounds?

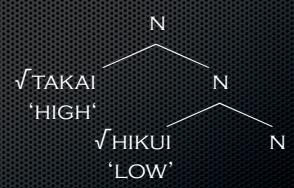
(1) Biru-no TAKAI-HIKUI-ga mondai da.
building-gen high-low-nom problem is
"The height of the building is the problem."

51

- Root compounding
- Exocentric compounds are in fact endocentric.

(1) A+A→N

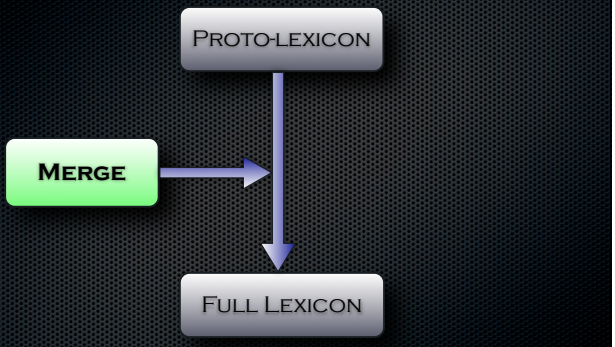
(2) √ + √ + N→N



52

- Evolution of the generative lexicon
- Syntax (recursive Merge) generates words. (Distributed Morphology)
- Lexical category = categorizer + root
  - v + √ DESTROY = destroy
  - n + √ DESTROY = destruction, etc.

53



54

- The issue of whether proto-language was holophrastic or synthetic is largely irrelevant.
- Word-like elements of proto-language (proto-words) could exist in the absence of syntax, providing materials to be combined later to form full words.

55

Syntactic Nature of 'Lexical' Verbs

(1) a. John gave Mary a book.
b. [vP John v [VP Mary V a book]]
c. [John CAUSE [Mary HAVE a book]]

(2) a. John gave a book to Mary.
b. [vP John v [VP a book V to Mary]]
c. [John CAUSE [a book GO-to Mary]]

56

Evidence from Developmental Data

CAUSE (2;0.4) ≥ HAVE (2;0.7) ≥
Double Obj verbs (2;1.6) >
GO (2;4.0) ≥ Dative Obj verbs (2;4.9)

- J. Viau

57

Merge in verb acquisition

"No verb is an island."

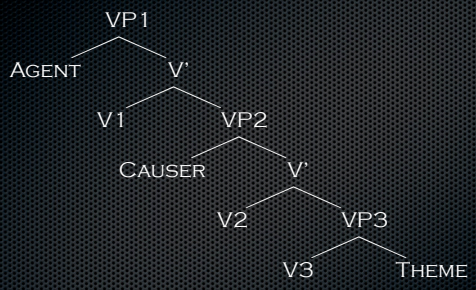
"Children start to use Merge already with their very first word combinations."

- A. Ninio

Children start to use Merge already with their very first words.

58

Three-Layered Split VP



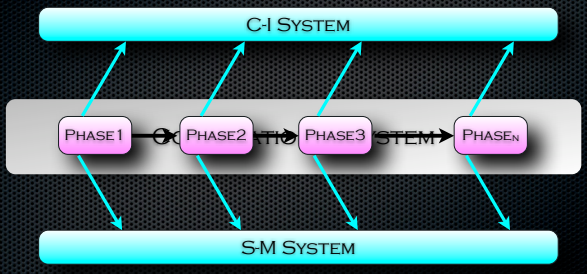
cf. [x DO [x CAUSE [y BECOME ...]]]

59

- Mapping to the C-I interface becomes straightforward.
- "Syntax carves out lexical and phrasal semantics."
- The evolution of the C-I interface and the lexicon depends on the evolution of recursive syntax.

60

Derivation by Multiple Phase Transfer



61

- Merge is at the root of human intelligence.

62

- Core-Merge + Label = Recursive Merge
- Core-Merge + Recursion = Recursive Merge
- Given that Label is already an instance of recursive Merge, where does its recursiveness come from? (EF is not an answer; it can only be a necessary condition.)

63

- General Recursive Capacity was extended to Core-Merge in the human brain to yield recursive Merge.

64

"All creatures are endowed with recursive motor machinery as part of their standard operating equipment."

"a critical step in acquiring our own distinctive brand of thinking was not the evolution of recursion as a novel form of computation, but the release of recursion from its motor prison to other domains of thought."

- M. Hauser

65

Main points made so far:

- Merge, subsuming both Move and Label, is the elementary computational device of human language.
- The uniquely human Recursive Merge evolved from the combination of Core-Merge and general recursive capacity, neither of which is unique to human language.
- The origins of these capacities, and the process of their combination, are the key issues of language evolution.

66

Part III

Towards a Comparative Study

67

Tools and Language: Action to Syntax

- Broca's area: common neural substrate for hierarchical organization in action and language

  - P. Greenfield 1991.

- Mirror neurons: for goal-directed manual action and language

  - P. Greenfield 2006.

68

- Gestural origin of syntax (?)

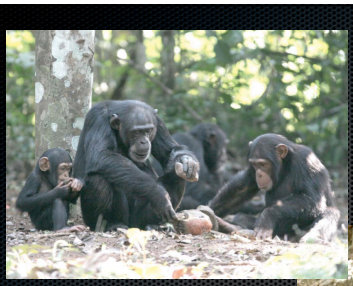
cf. M. Corballis: "Speech evolved from manual gestures."

69

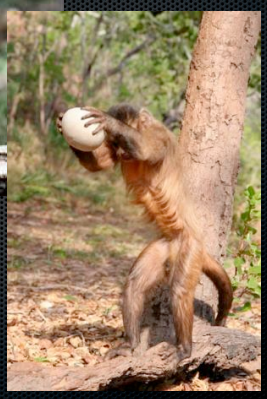
COURTESY OF THE NEW YORK PUBLIC LIBRARY

PROBLEM SOLVING IN CHIMPS, in this case, stacking boxes to reach bananas, was first documented by Wolfgang Köhler around the time of World War I.

70



71

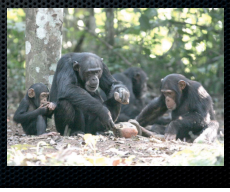


72

HAMMER NUT ANVIL

MERGE (NUT, ANVIL) → {NUT, ANVIL}

MERGE (HAMMER, {NUT, ANVIL}) → {HAMMER, {NUT, ANVIL}}



73

I. PAIRING STRATEGY

CORE-MERGE

THE BOY

74

II. POT STRATEGY

POT-MERGE:

JOHN SAW MARY

75

III. SUBASSEMBLY STRATEGY

SUB-MERGE:

THE BOY SAW MARY

76

- Pot-Merge:
  - Merge (A,B):
    A attracts B, forming {A,B}=A.
  - Merge (A,C):
    A attracts C, forming {{A,B},C}=A.
- Sub-Merge:
  - Merge (A,B):
  - A attracts B, forming {A,B}=A.
  - Merge (A,C):
  - C attracts A, forming {{A,B},C}=C.

77

Swedish: barn bok klub:

English: child book club:

- T. Roeper & W. Snyder

78

- potential problem:

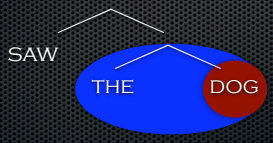
If 'book' and 'child' are syntactically complex, right-branching compounding already requires Sub-Merge.

79

Root compounding

80

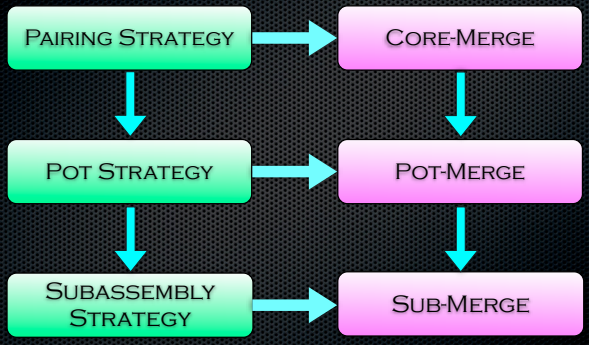
- Given that a lexical category is syntactically complex, Merger of lexical categories always takes place in the form of Sub-Merge.



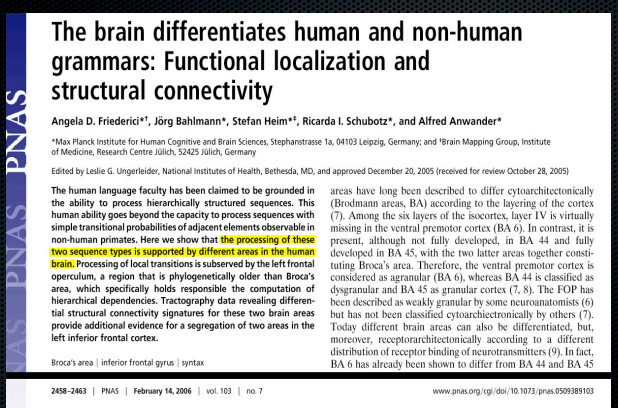
81

- It was the emergence of Sub-Merge that gave rise to full human language.

82



83



The brain differentiates human and non-human grammars: Functional localization and structural connectivity

Angela D. Friederici*†, Jörg Bahlmann*, Stefan Heim*‡, Ricarda I. Schubotz*, and Alfred Anwander*

*Max Planck Institute for Human Cognitive and Brain Sciences, Stephanstrasse 1a, 04103 Leipzig, Germany; and ‡Brain Mapping Group, Institute of Medicine, Research Centre Jülich, 52425 Jülich, Germany

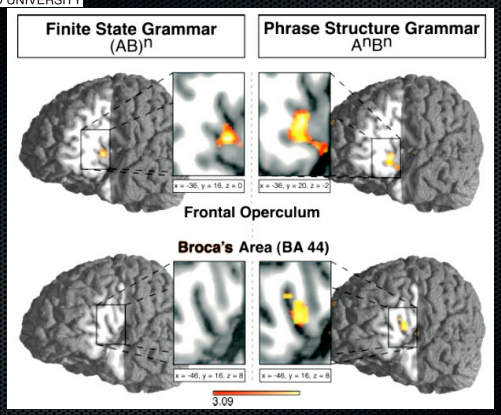
Edited by Leslie G. Ungerleider, National Institutes of Health, Bethesda, MD, and approved December 20, 2005 (received for review October 28, 2005)

The human language faculty has been claimed to be grounded in the ability to process hierarchically structured sequences. This human ability goes beyond the capacity to process sequences with simple transitional probabilities of adjacent elements observable in non-human primates. Here we show that the processing of these two sequence types is supported by different areas in the human brain. Processing of local transitions is subserved by the left frontal operculum, a region that is phylogenetically older than Broca's area, which specifically holds responsible the computation of hierarchical dependencies. Tractography data revealing differential structural connectivity signatures for these two brain areas provide additional evidence for a segregation of two areas in the left inferior frontal cortex.

Broca's area | inferior frontal gyrus | syntax

areas have long been described to differ cytoarchitectonically (Brodmann areas, BA) according to the layering of the cortex (7). Among the six layers of the isocortex, layer IV is virtually missing in the ventral premotor cortex (BA 6). In contrast, it is present, although not fully developed, in BA 44 and fully developed in BA 45, with the two latter areas together constituting Broca's area. Therefore, the ventral premotor cortex is considered as agranular (BA 6), whereas BA 44 is classified as dysgranular and BA 45 as granular cortex (7, 8). The FOP has been described as weakly granular by some neuroanatomists (6) but has not been classified cytoarchiectronically by others (7). Today different brain areas can also be differentiated, but, moreover, receptorarchitectonically according to a different distribution of receptor binding of neurotransmitters (9). In fact, BA 6 has already been shown to differ from BA 44 and BA 45

84



- A. D. Friederici et al.

Two Neuronal Circuits for Processing Syntactic Complexity

- Finite State Grammar ($(AB)^N$):

  Ventral Premotor Cortex (vPMC, BA6) & Deep Frontal Operculum (FO)

- Phrase Structure Grammar (A^NB^N):

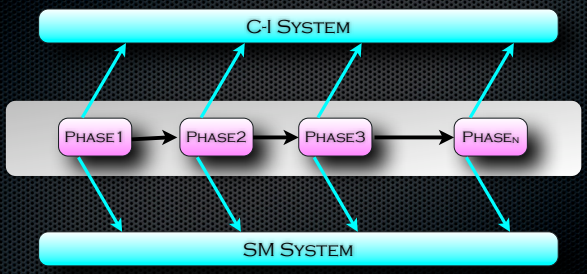
  BA44/45 (Broca's Area) & Posterior Part of Superior Temporal Gyrus (STG)

vPMC/FO phylogenetically older than Broca's Area

- A. D. Friederici & J. Brauer

- Core-Merge is phylogenetically older (and ontogenetically earlier) than Sub-Merge.
- Ph(r)asal movement is a form of Sub-Merge, a later innovation than Core-Merge.
- Move for externalization (communication).

Transfer as Sub-Merge?
(recursive mapping to the interfaces)



Phase = derivational chunk

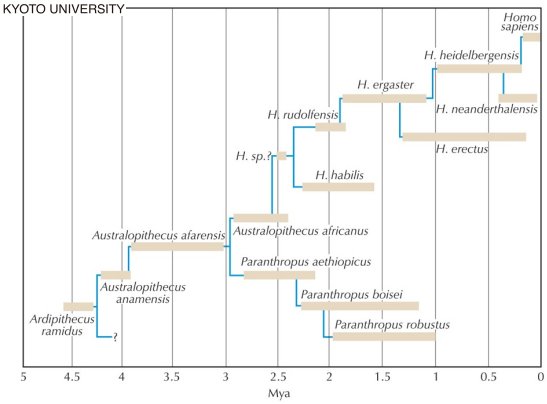


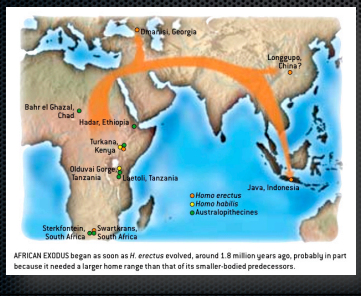
FIGURE 25.7. Postulated time spans and relationships of hominin species.

25.7, adapted from Johanson D. et al. 1996. *From Lucy to Language*, p. 38, with permission of Nēvraumont Publishing Co.

89

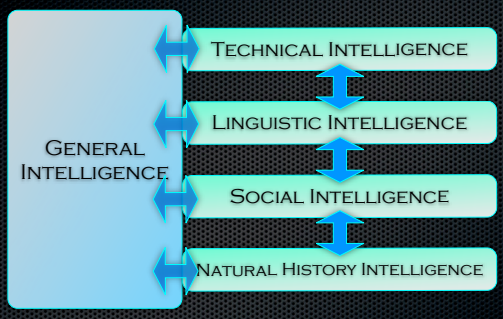
"THE DISPERSION OF HUMANS OVER THE WORLD MUST POST-DATE THE EVOLUTION OF LANGUAGE, SINCE THERE IS NO DETECTABLE DIFFERENCE IN BASIC LANGUAGE CAPACITY AMONG CONTEMPORARY HUMANS."

- N. CHOMSKY



AFRICAN EXODUS began as soon as *H. erectus* evolved, around 1.8 million years ago, probably in part because it needed a larger home range than that of its smaller-bodied predecessors.

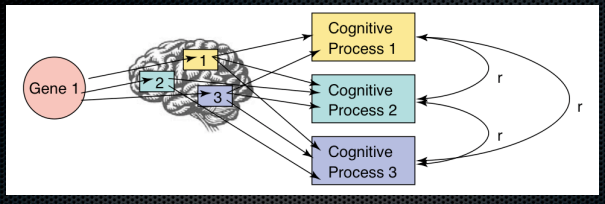
90



- THREE PHASES FOR THE EVOLUTION OF THE MIND

S. MITHEN 1988. THE PREHISTORY OF THE MIND.

91

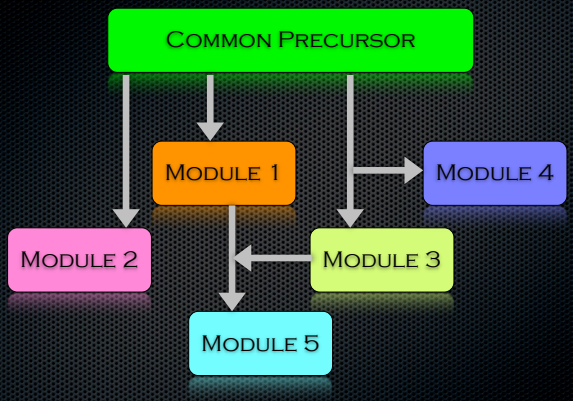


Mechanism 3

A gene influences several areas of the brain, and each area affects several cognitive processes

Y. KOVAS & R. PLOMIN 2006. GENERALIST GENES: IMPLICATIONS FOR THE COGNITIVE SCIENCES. TRENDS IN COGNITIVE SCIENCES 10.

92



cf. G. Marcus: "Descent-with-modification modularity"

93

Main points made so far:

- Syntax evolved from manual action.
- Sub-Merge is the recursive engine of human syntax, a combination of pot-Merge and Subassembly strategy of action grammar.
- The fact that the Merge-based derivational model makes this kind of comparative study possible demonstrates the advantage of adopting minimalist syntax for evolutionary studies of language.
- It also shows that evolutionary linguistics and theoretical linguistics are tightly connected.

94

"To create is to recombine."

- F. Jacob

"To create is to Merge."

- A generative biolinguist

95